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Design and Evaluation of a 27 MHz Microcontroller-Based Wireless Communication System for Disaster Mitigation

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ABSTRACT

Background: Indonesia is a region frequently affected by natural disasters. During such events, critical infrastructure often suffers severe damage, and rebuilding it to a fully operational state requires a considerable amount of time. One of the key impacts of natural disasters is the damage to telecommunication networks, which necessitates rapid restoration efforts. Radio communication systems offer a viable solution for emergency communication during such times.
Aims and Methods: This study presents the design of an early warning system simulator aimed at mitigating the impacts of disasters in vulnerable areas. The proposed system utilizes the ATmega328 microcontroller as the main data processor, an RX-2B module to receive 27 MHz radio signals transmitted by a TX circuit, and a TX-2B module to send wireless commands via 27 MHz radio frequency to the RX circuit. Additional components include a buzzer as an alarm indicator and a 16x2 LCD display to show patient room information. The objective of this research is to develop a microcontroller-based early warning system simulator for disaster-prone regions.
Results: Based on the testing results, data transmission was successfully achieved at distances over 50 meters in indoor environments. In outdoor environments, reliable data communication was maintained at distances of up to 70 meters.

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1. Introduction

Indonesia is a region that frequently experiences natural disasters. During such events, critical infrastructure often suffers severe damage, and the reconstruction process requires significant time to restore conditions to normal (Danang et al., 2019). One of the major impacts of disasters is the disruption of telecommunication networks, which necessitates urgent restoration (Muhammad et al., 2018). A viable communication technology for post-disaster recovery, such as after an earthquake, is radio communication utilizing high-frequency (HF) bands. HF radio communication systems offer several advantages in terms of signal propagation, including the ability to cover long distances, ease of implementation, and lower cost compared to satellite communication systems. However, HF radio communication is significantly influenced by factors such as increased channel bandwidth and radio frequency (Jian Wang et al., 2022; Warrington et al., 2012). Therefore, HF systems are well-suited for application in disaster mitigation communication channels (Yang et al., 2019; Praveen Kumar et al., 2019).

One type of HF radio wave propagation is the sky wave. In this mode, the transmitted signal is reflected by the ionospheric layer, allowing it to reach distant receivers. With sufficiently high transmission power, signals reflected between the ionosphere and the Earth's surface can cover very long distances (Jinlong Wang et al., 2018; Maslin, 2021).

Developed a high-frequency ionospheric wideband propagation simulation relevant to HF spread-spectrum communication and other HF applications such as digital broadcasting and over-the-horizon radar. The simulation was constructed based on solving the governing equations for pulse signal propagation through time-varying ionospheric fluctuations (Fechtel, 1993).

Measurements of HF channel characteristics have also been conducted in Europe. One resulting model is the Logit Laycock-Gott model, which requires 25 parameters determined by fitting the model to measurement data across various locations. These measurements revealed that frequency dependence is time-invariant and location-independent (Castellanos et al., 2021).

2. Methods

The research was carried out at the campus of the Muhammadiyah Aceh College of Health Sciences, specifically within the Electronics Laboratory. The methodology involved a comprehensive review of literature related to microcontroller-based programming and electronic systems, aimed at developing a wireless communication device for disaster mitigation in regions that lack access to cellular communication networks.

The communication device is designed to automatically transmit a message or command when the call button is pressed and to delete the message or command when the stop button is activated. This device is intended for use in areas not covered by cellular networks, allowing it to operate independently in disaster-affected regions and thereby facilitating the evacuation of victims.

The system operates by sending a signal or call command when the transmission button is pressed; this signal is received on the other end and displayed on an LCD screen. A green LED serves as an indicator that a disaster victim has been located. For further communication, an encoded signaling system can be utilized.

Components of the Device :

a) Arduino Uno is a microcontroller board based on the ATmega328. This board features 14 digital input/output pins (6 of which can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, and a reset button. The Arduino Uno contains all the necessary components to support the microcontroller. It can easily be connected to a computer via a USB cable or powered using an AC-to-DC adapter or battery to initiate operation.

b) ATMega328 is a microcontroller developed by Atmel that features a RISC (Reduced Instruction Set Computer) architecture, which enables faster data execution processes compared to CISC (Complex Instruction Set Computer) architecture .
c) TX/RX-2B Module : The TX/RX-2B module consists of a transmitter (TX-2B) and a receiver (RX-2B) integrated circuit pair. The TX-2B is designed to send control signals, while the RX-2B is designed to receive and process them. TX-2B has 14 pins, whereas RX-2B has 16 pins. Radio control communication is carried out using radio waves, where each command is represented by a specific number of pulses: forward (8 pulses), left (16 pulses), right (32 pulses), and backward (64 pulses). Combined commands are possible by summing pulses, such as forward + left = 24 pulses. The effective communication range of this remote control system is approximately 20 meters.
d) A push button switch is a simple device/switch that functions to connect or disconnect the flow of electric current with a momentary (unlock) operation system. The unlock system means that the switch acts as a connector or interrupter of the electrical current only while the button is pressed, and returns to its normal state when the button is released.
e) Liquid Crystal Display, commonly known as LCD, is a display device typically used to show simple ASCII characters and images on digital devices such as watches, calculators, and others. A simple description of the working principle of an LCD matrix, specifically a Twisted Nematic (TN) Liquid Crystal Display, involves two polarized materials, two glass substrates, an electrode pattern to define pixels, and an Integrated Circuit (IC) to address rows and columns. To determine the position of each pixel, a grid made of Indium Tin Oxide (a semi-transparent metal oxide) is formed, and current is applied to specific pixel positions to change the orientation of the liquid crystal material. This change in orientation alters the pixel from white to black. The orientation controls whether light is transmitted or blocked; if the light is blocked, the area appears dark.
f) A buzzer is an electronic component that functions to convert electrical vibrations into sound vibrations. Fundamentally, the working principle of a buzzer is similar to that of a sound speaker. The buzzer consists of a coil mounted on a diaphragm; when current flows through the coil, it becomes an electromagnet. The coil is attracted inward or outward depending on the direction of the current and the polarity of the magnet. Since the coil is attached to the diaphragm, every movement of the coil causes the diaphragm to move back and forth, which vibrates the air and produces sound. Buzzers are commonly used as indicators to signal that a process has been completed or that an error has occurred in a device.

2.1 Block diagram

The working principle of the block diagram shown in Figure 1 begins with the 220V AC mains voltage supplied to two power supply units: Power Supply 1 and Power Supply 2. Power Supply 1 converts the input into 3V DC, which is then supplied to the Transmitter module. Power Supply 2 converts the input into 5V DC and distributes it to the Receiver module, the Arduino ATMega328 microcontroller, and the LCD display. The Push Button Call serves as a trigger command for the Transmitter module to emit a 27 MHz signal with a specific number of pulses. This signal is received by the Receiver module, which subsequently sends a command to the Arduino ATMega328 to display information on the LCD. In addition, the system activates an LED as a visual indicator, and a buzzer functions as an alarm.

The data used for this study consists of two types of data, namely primary data and secondary data. For primary data, it is the result of an assessment obtained from interviews and direct assessments of the waste alms program. Secondary data consists of assessment indicators, assessment parameters, assessment scale values, and the number of waste management programs in the Special Region of Yogyakarta Province, which come from literature studies, technical instructions, and regulations that support this study. When the call button is pressed twice, the LED turns red, indicating that the user is in urgent need of assistance. At the same time, the buzzer is activated to serve as an audio alarm.

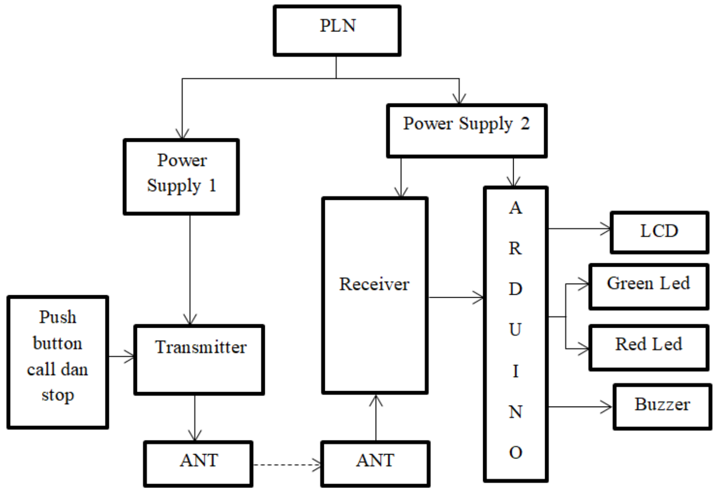

Figure 1. Block Diagram of system

2.2 Flow chart

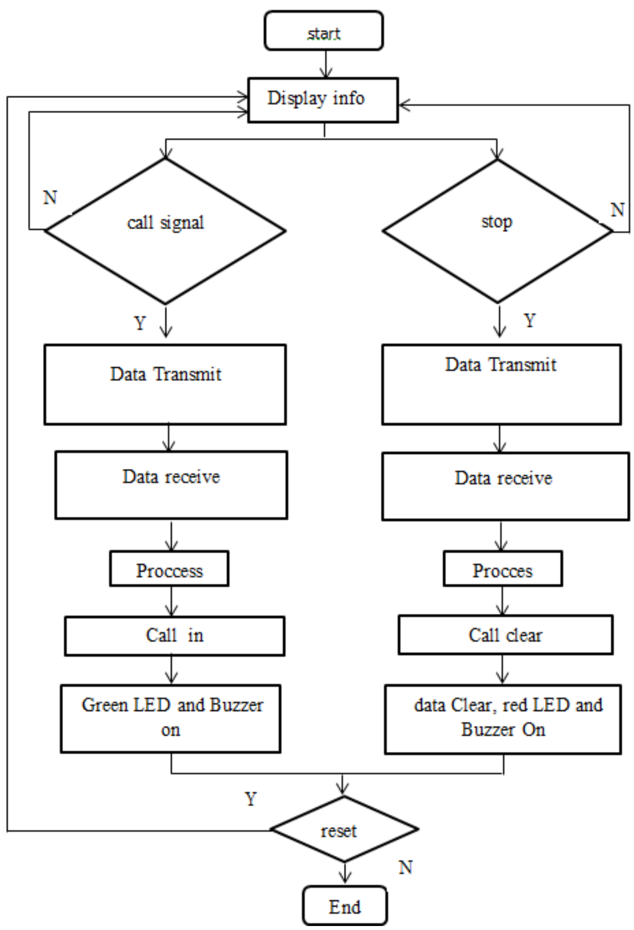

Figure 2. Flow chart of system

Figure 2 illustrates the flowchart of commands executed by the Arduino Uno microcontroller. The process begins with powering on the system. Once initialized, the LCD displays a message indicating that the device is ready for use, prompting the user to press either the Call or Stop button. If the Call button is pressed once, the system will activate a green LED, indicating that a regular assistance request has been made. If the Call button is pressed twice, the system will activate a red LED, signaling an emergency call. Pressing the Stop button will cancel the call.

3. Results and Dicussion

3.1 The effect of distance on signal transmission performance

In this experiment, several parameters of the communication system were measured, including Free Space Path Loss (FSPL), Received Power (Pr), Noise, and Signal-to-Noise Ratio (SNR) at various distances. The purpose of this test is to observe how distance affects signal quality degradation in a wireless communication system.The measurement data are presented in Table 1.

Table 1. Measurement Results of FSPL, Pr, Noise, and SNR at Various Distances

Distance (m)	FSPL (dB)	Pr (dBm)	Noise (dBm)	SNR (dB)
10	31.1	-23.1	-132.9	109.8
20	37.1	-29.1	-132.9	103.8
30	40.6	-32.6	-132.9	100.3
40	43.1	-35.1	-132.9	97.8
50	45.5	-37.5	-132.9	95.4
60	47.2	-39.2	-132.9	93.7
70	48.9	-40.9	-132.9	92.0

3.1.1 The Impact of Distance on FSPL and Pr

Based on the data in Table 1, it is evident that the FSPL value increases as the distance between the transmitter and receiver increases. This increase is consistent with the Free Space Path Loss theory, which states that power loss in free space increases logarithmically with distance. For example, at a distance of 10 meters, FSPL is 31.1 dB, while at 70 meters it increases to 48.9 dB.

This increase in FSPL directly affects the received signal power (Pr), which decreases as the distance increases. At 10 meters, the received signal power is -23.1 dBm, dropping to -40.9 dBm at 70 meters. This is due to the greater loss in signal strength as it propagates through open space.

3.1.2 SNR With Constant Noise Level

The measured noise level remains constant at -132.9 dBm across all distances. This indicates that the noise affecting the system originates from a consistent or controlled source in the testing environment. Therefore, the changes in SNR (Signal-to-Noise Ratio) are solely due to variations in received signal power (Pr).

The SNR values decrease as the distance increases. This decline indicates a reduction in signal quality, as the received signal becomes weaker relative to the constant noise floor. At 10 meters, the SNR reaches 109.8 dB, decreasing to 92.0 dB at 70 meters. Although the SNR remains within acceptable limits, the downward trend suggests potential degradation in communication quality over longer distances or under additional environmental interference.

The measurement results show that a clear inverse relationship between signal strength and transmission distance in both indoor and outdoor environments using a 27 MHz radio frequency communication system. In indoor scenarios, signal strength degrades rapidly due to physical obstructions such as walls and ceilings, which introduce attenuation and multipath interference. As shown in the graph, signal strength decreases from 100% at the transmitter to approximately 30% at 50 meters—the maximum reliable distance indoors. This steep degradation highlights the limitations of RF communication within buildings and suggests the need for additional infrastructure, such as repeaters or signal amplifiers, to ensure consistent performance.

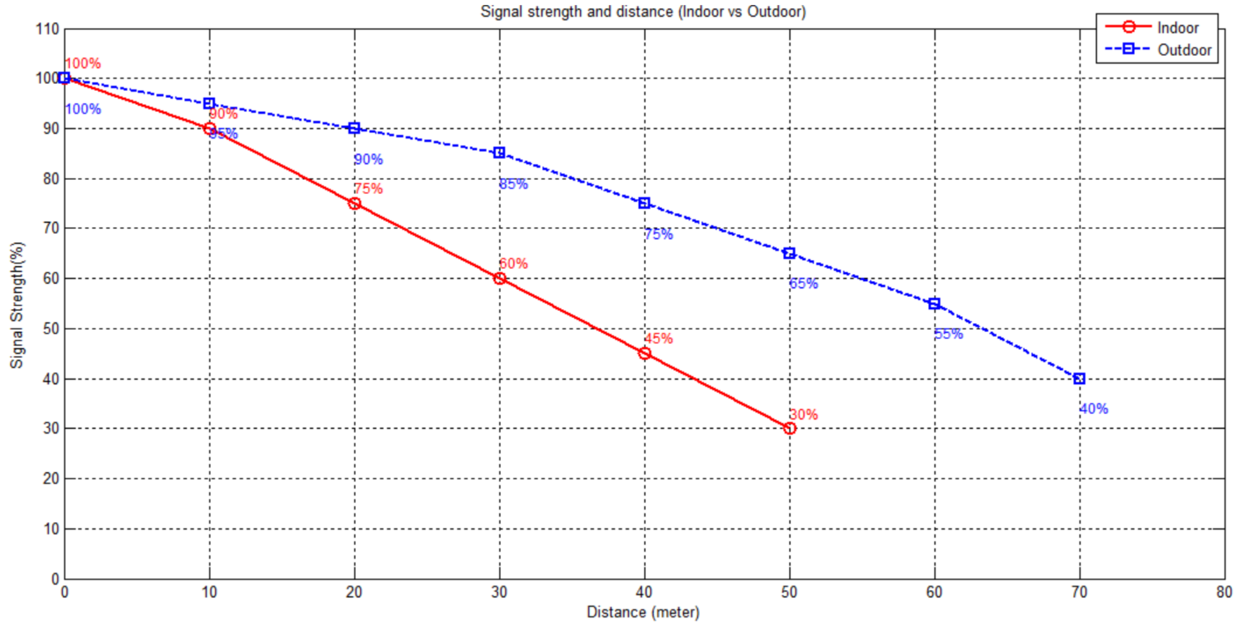

Figure 3. Graph of signal strength Vs Distance (indoor and outdoor)

As shown in the graph, signal strength decreases from 100% at the transmitter to approximately 30% at 50 meters—the maximum reliable distance indoors. This steep degradation highlights the limitations of RF communication within buildings and suggests the need for additional infrastructure, such as repeaters or signal amplifiers, to ensure consistent performance.

In contrast, the outdoor environment demonstrates a more gradual reduction in signal strength, maintaining above 40% even at 70 meters. The absence of significant obstructions allows for better line-of-sight propagation, making outdoor RF communication more stable and reliable over longer distances. This finding supports the system's suitability for emergency communication in open areas, where maintaining coverage is critical. The comparative analysis confirms that environmental conditions significantly affect RF signal behavior, and system deployment should be adapted accordingly to maximize reliability in both indoor and outdoor settings.

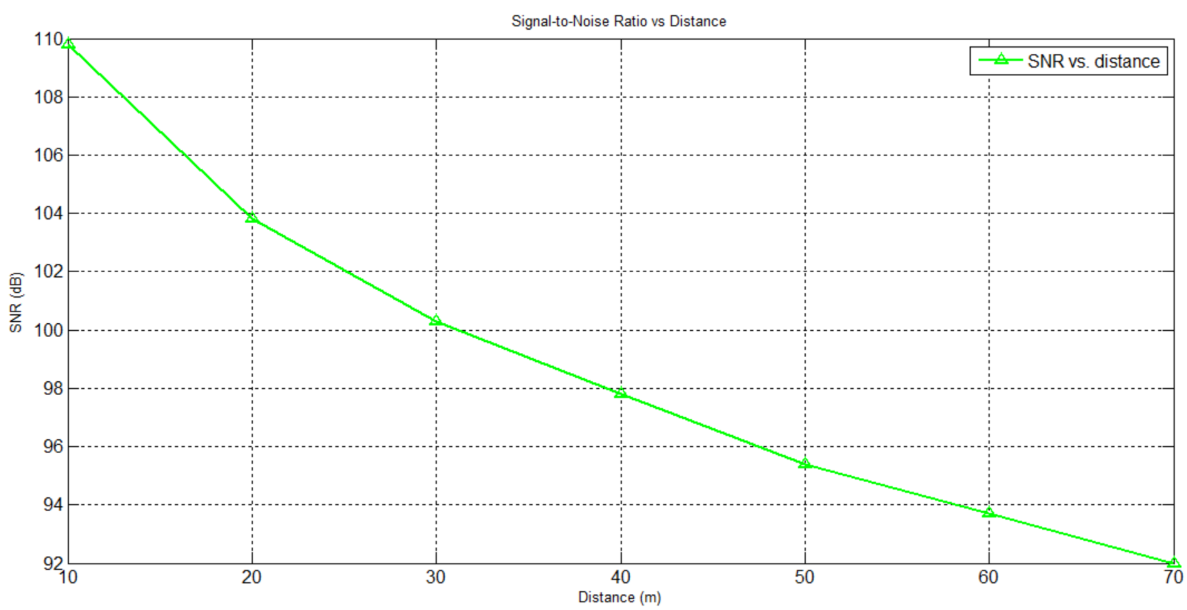

Figure 4. Graph of SNR Vs Distance

Figure 4 illustrates the relationship between Signal-to-Noise Ratio (SNR) and distance. At a distance of 10 meters, the SNR reaches approximately 110 dB, indicating a very strong and clear signal reception. As the distance increases, the SNR gradually decreases. At 40 meters, the SNR drops to 97.8 dB, and continues to decline, reaching 92 dB at 70 meters. This downward trend clearly demonstrates that the performance of the communication system degrades as the receiver moves farther from the transmitter. Although the SNR values remain high and well above typical operational thresholds, the observed decline emphasizes the impact of distance on signal quality in practical radio communication environments.

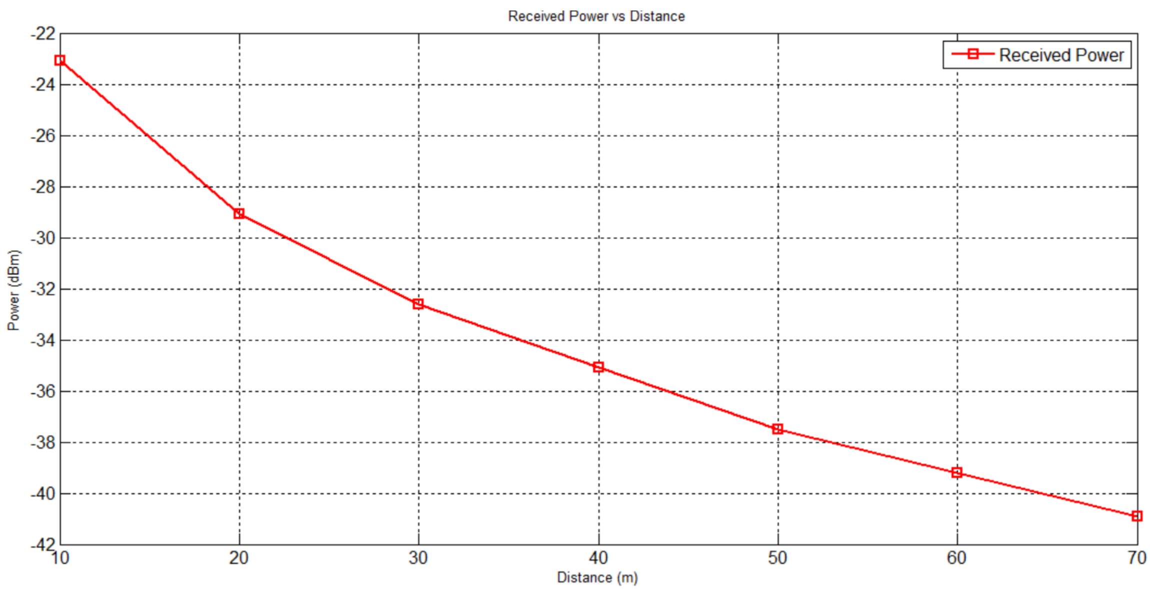

Figure 5. Graph of Power receiver Vs Distance

In Figure 5, the received power level is shown to decrease progressively from -23 dBm at a distance of 10 meters to approximately -41 dBm at 70 meters. This gradual decline in signal strength is a direct result of increasing free-space path loss as the transmission distance grows. Despite the decreasing power, the signal remains detectable and above the noise floor within the tested range, suggesting that the system is still operational up to 70 meters in outdoor environments. However, the noticeable attenuation implies that the signal quality deteriorates with distance, and the 70-meter mark represents the practical limit of reliable communication for this system in open areas. Beyond this point, the received power may fall below the sensitivity threshold of the receiver, potentially leading to data loss or communication failure. These findings highlight the importance of considering path loss and receiver sensitivity in designing wireless communication systems for disaster mitigation, especially in scenarios where range and reliability are critical.

4. Conclusions

This research addressed the need for a reliable communication system in disaster-prone regions, where conventional telecommunication infrastructure is often rendered inoperable. By developing a microcontroller-based early warning system simulator utilizing 27 MHz radio frequency modules, the study successfully met its objective of providing a simple, low-cost, and deployable solution for emergency communication. The system's ability to perform stable data transmission in both indoor and outdoor environments supports its suitability for use during post-disaster scenarios, where rapid response and infrastructure independence are critical.The results confirm that radio-based systems built with readily available components like the ATmega328 and TX/RX-2B modules can serve as effective alternatives when existing networks fail. Future work may explore the integration of real-time sensor data, multi-node network configurations, and long-range communication strategies to enhance the system's scalability and responsiveness in larger or more complex disaster settings.

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6. Authors Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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